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ECOSYSTEM APPROACH TO ESTIMATION OF LONG-TERM YIELD OF COD IN THE BARENTS SEA

by

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Introduction

Existing management strategy for cod stock in the Barents Sea is based on the precautionary approach concept employed in ICES. According to this concept, the fishing mortality is set depending on spawning stock biomass and such biological reference points as B_{lim}, B_{pa}, F_{lim} and F_{pa}, which are expressed in values of fishing mortality and biomass of spawning stock. The major advantage of these rules is that they are simple and the main drawback of this approach is that it ignores effect of interannual variations of ecosystem factors on stock dynamics. The values of reference points remain constant despite the current or expected situation in the ecosystem. At the same time, productivity of the stock and its reproductive capacity will significantly differ depending on feeding resources, thermal conditions and abundance of predators or feeding competitors (Blindheim, Skjoldal, 1993; Filin, 2004a). Our knowledge proves that in many cases ecosystem factors have a decisive effect on recruitment, growth and mortality of commercial marine organisms (Skjoldal, 1990; Filin et al., 2003). Underestimation of these factors in justification of harvest strategy can lead to both critical overfishing and groundless reduction of a possible catch.

The stock management strategy is based on expected estimate of long-term yield. Such estimates are used to set optimal harvest intensity according to the accepted management targets. Management strategy for cod stock based on existing concept of precautionary approach is probably able to ensure conditions when the risk of critical stock depletion will not exceed allowable limits. However, the following questions arise. Is this harvest strategy good enough to ensure maximum sustainable yield of cod considering interannual variations in the ecosystem of the Barents Sea? Do the existing precautionary rules for deciding on TAC of cod correspond to the principals of rational harvest of this stock, taking into account natural fluctuations of the population under the influence of ecosystem factors? Is it possible to increase harvest efficiency of cod stock in the Barents Sea by improving the management strategy implementing ecosystem approach in harvest management without breaking the accepted precautionary principle?

Nowadays, these questions still lack clear answer and non of the existing opinions can be accepted as well-grounded since no methodical basis of ecosystem approach for estimation of long-term sustainable yield of cod in the Barents Sea is developed.

Considering the urgency and practical importance of this issue, a 10-year research programme in the framework of joint Russian-Norwegian project on development of optimal harvest strategy for marine organisms in the Barents Sea taking into account their interactions and the effect of ecosystem factors was adopted at the 33rd session in 2004. At the first stage of this work, we should focus on cod.

The purpose of this paper is to ground methodical approaches to development of harvest strategy for cod in the Barents Sea that is based on estimates of long-term yield taking into account the effect of ecosystem factors on stock dynamics.

Long-term yield and ecosystem strategy for harvest of cod in the Barents Sea

The only method for estimation of expected long-term yield is mathematic modelling. In the mostly simple form, it can be implemented under conditions of equilibrium state of the population, which means that mortality corresponds to recruitment of fishing stock that has constant biological parameter. Based on these assumptions, a maximum sustainable yield (MSY) can be calculated and its value is often considered as one of the reference points used in harvest management. It is obvious that using this approach the effect of ecosystem factors on stock dynamics is completely neglected.

A more realistic calculation of long-term yield can be obtained by using variables from year to year population parameters that are randomly chosen from a set of historic data. This approach allows us to take into account natural variability of population parameters when modelling the stock dynamics and can give stochastic estimates of long-term yield after repetitive runs of the model. However, it cannot ensure an adequate estimate of population parameters variation under the influence of environmental changes since it does not expose such dependences, but only indirectly allows for it. Such an estimate can be obtained only by using multispecies and ecosystem based models that take explicitly into account the effect of species interaction and oceanographic factors on population parameters of the stock, which define the productive capacity of the species (Tjelmeland, Bogstad, 1998; Filin, 2004b).

The development of cod harvest strategy based on the estimation of long-term yield taking into account the effect of ecosystem factors shall consist of the following stages:

1) define the management targets;

2) specify ecosystem factors for simulation;

3) develop models for stock management that take into account the effect of species interaction and ecosystem factors on stock dynamics;

4) develop stochastic ecosystem scenarios for testing the harvest strategy;

5) perform simulations of stock dynamics and statistic analysis of the obtained data;

6) develop rules for stock harvest that take into account adjustable fishing effort depending not only on the state of the stock but also on the situation in the ecosystem;

7) assess economic efficiency of the stock harvest using the developed strategies.

Management targets

For Northeast Arctic cod, the existing harvest strategy is aimed at maximum and stable long-term yield. From the ecosystem perspective, these aims should be considered as hardly compatible. No measures for harvest management are able to eliminate interannual natural abundance fluctuations of commercial species since they are caused by large-scale oceanic processes that cannot be controlled by human. Therefore, the most effective harvest strategy in terms of maximum long-term yield is a strategy that takes explicitly into account ecosystem mechanisms of the stock dynamics when estimating fishing mortality. In order to obtain the highest long-term yield we should follow natural stock dynamics instead of trying to smoothen it applying certain management measures.

However, such harvest strategy is not optimal in the economic perspective since industry is interested in interannual stability of cod catches. In order to eliminate these contradictions we should define allowable limits of interannual variations of cod catches for calculation of maximum long-term yield. The consequences for stock dynamics and fishing efficiency under different variants of these conditions should be analysed while simulating the stock harvest strategies.

Identifying ecosystem factors for simulation

When identifying the ecosystem factors for simulation of harvest strategy we should consider both the effect on the dynamics of cod stock and availability of data that is necessary for simulation. The results of many researches show that it is thermal conditions and the situation in capelin stock that have the greatest effect on growth, maturation and recruitment of cod (The Barents Sea cod…, 2003). Quantitative estimates of effect of these factors on cod population parameter are well documented and this effect is better studied then effects of other factors. The dynamics of capelin stock abundance in the Barents Sea has been monitored since 1972, while temperature observations have been carried out since the beginning of the last century. Therefore, water temperature and capelin stock biomass were chosen as main ecosystem parameters that effect natural dynamics of cod stock in the Barents Sea.

Cod feed not only on capelin but also on other species. Cod is a polyphage species and it can feed on more than 200 species of the Barents Sea (The Barents Sea cod…, 2003). When it lacks capelin cod can switch to own juveniles, shrimps, herring, polar cod and euphausiids. The abundance of Norwegian spring-spawning herring to large extend is opposite to that of capelin. These two species are close to each other in nutritional value and we can expect that when abundance of capelin is low, juveniles of herring can substitute capelin in cod diet. According to the publications herring was of great importance for cod in 1930s-1960s (The Barents Sea cod…, 2003). However, in the next period the importance of herring was relatively low, even in the years when its abundance was high. Nevertheless, juveniles of herring should be considered as an important ecosystem component for cod stock in the Barents Sea taking also into account negative impact of herring on capelin stock.The most catastrophic consequences for feeding recourses of cod in the Barents Sea will occur when periods of low abundance of capelin will overlap with the absence of spring-spawning herring.

According to the existing estimates, cannibalism is the main contributor to cod mortality caused by predation (Dolgov, 1999). However, predation by marine mammals should also be considered as an ecosystem factor that can affect stock dynamics of cod (Bogstad et al., 2000). The predation of marine mammals on capelin, polar cod and herring can also have important consequences for cod stock. Unfortunately, the possibility to incorporate the effect of marine mammals into simulations is limited due to incomplete data. Therefore, the activities to increase the collection of necessary data on feeding and migrations of marine mammals are planned in the framework of joint research programme on estimation of optimal harvest strategy of marine organisms in the Barents Sea. Nowadays, among over 20 species of marine mammals that occur in the Barents Sea, only minke whale and harp seal can be considered as potential species for simulations.

Development of multispecies and ecosystem models for cod stock management

Development of models to improve harvest management of bioresources in the Barents Sea based on species interactions started in IMR in mid-80s and in PINRO in the early 1990s of the last century. At the first stage, the work was focused on complex models that included maximum number of species interacted according to their trophic relations. The time intervals used in modelling were minimal (one or three months) and in some cases, the dividing the Barents Sea in areas was also used. On the one hand, the model became more realistic but on the other hand, the result was the opposite since it required employing a number assumptions cause by insufficient knowledge and incomplete data.

This approach was used in IMR to develop such models as MULTSPEC, AGGMULT and Systmod. In PINRO this approach was employed for development of MSVPA model (Tjelmeland, Bogstad, 1998, 2000; Hamre, Hatlebakk, 1998; Korzhev, Dolgov, 1999). All these models can give quantitative characteristics of species interaction of cod in the Barents Sea and can be useful to solve theoretical problems of multispecies harvest management. However, the use of these models for practical tasks of estimating long-term yield and biological reference points for cod fishery is limited by high level of uncertainty in calculations due to assumptions employed in the models and incomplete data.

Therefore, since the second part of the 1990s some more simple, in structural sense, models have been prioritised. They only reflect separate elements of species relations (not interactions) between main species targeted by fisheries in the Barents Sea, which is cod and capelin. IMR has developed and uses in practical work Bifrost model, which is oriented to capelin (Gjøsæter et al., 2002). PINRO has developed STOCOBAR model that describes dynamics of cod stock in the Barents Sea and is based on multispecies approach (Filin, 2004b). Both models can be adapted for estimation of long-term yield of cod in the Barents Sea taking into account species interactions.

Bifrost and STOCOBAR models simulate mechanisms of the processes that define dynamics of modelled biological parameter. In this sense, they are different from the models that based on regression equations. Incorporation of regression equations that describe elements of species interactions, into a single species model of the stock dynamics is probably the simplest way to employ multispecies approach in development of harvest management model. Therefore, at the first stage in the framework of joint programme employing the principal of succession in the transition from single species model to multispecies model it is planed to develop EcoCod model, which will incorporate correlation dependences of cod population parameters on ecosystem factors. This model shall be a successor of the joint single species model CodSim used for estimation of long-term yield of cod. The CodSim model will be modified by incorporating regression equations in the calculation algorithms. These equations describe correlation dependences of cod growth, maturation, recruitment and natural mortality on ecosystem parameter.

Development of stochastic ecosystem scenario

The identification of the scenario should be based on targets of model analysis. Proceeding from this, a number of ecosystem parameters for the scenario and the range of their variations are set. Ecosystem scenarios based on historic data should be employed for estimation of biological reference points in harvest management. Prognostic scenarios cannot be applied for this purpose. The main indicator that characterises ecosystem scenario is its capacity to give a realistic picture exposing a match between variations of the ecosystem parameter based on a scenario and historic data.

The scenario of thermal condition development does not depend on scenarios of development of biological processes and it should be based on short-term cycles and long-term warm-cold periods obtained from historic data taking into account occasional deviations from general pattern. The thermal scenario is based on historic data set. For stochastic scenario, the data can be selected by several means:

- random selection;
- random selection in the given interval;
- in successive order combining warm, cold and moderate periods, based on data randomly selected in the given interval.

The scenario of development of thermal conditions should determine scenarios of feeding resources dynamics for cod that are also based on historic data on capelin stock biomass and other prey species for cod in the Barents Sea.

Simulations of stock dynamics and statistic analysis of the results

Simulations should be used to study the necessity to apply different approaches to the harvest management depending state of the ecosystem. For this purpose, it is necessary to have comparative data obtained from modelling of productivity of cod stock under different scenarios of development of thermal conditions, abundance of prey species and predators. In particular, it is necessary to conduct a comparative analysis of cod stock dynamics in warm, moderate and cold periods with different levels of capelin stock. Fishing mortality that ensures maximum long-term yield should be estimated for each of these scenarios. Besides, we should take into account uncertainties connected to the prediction of dynamics of ecosystem parameters.

The most convenient way to present the results of statistic analysis of model calculations is in form of probability estimates of possible variations of the modelled parameters. Applying this method to take into account uncertainty, the probability can be presented in from of a risk estimate of undesirable consequences for the stock and harvest implementing a testing strategy. Especially it concerns the probability of declining of stock level bellow the established threshold level. In order to perform risk analysis, the results of multiple runs of stochastic model will be analysed.

Improvement of harvest control rules for cod based on ecosystem approach

Estimation of biological reference points (B_{lim}, F_{lim}, B_{pa} and F_{pa}) based on multispecies and ecosystem models will probably become the first step forward in implementing ecosystem approach for existing scheme of TAC calculation. From the ecosystem point of view the stock harvest level should vary depending not only on the state of the stock but also on the ecosystem parameters that determine recruitment, growth and natural mortality of the species. This will require changing over to a differentiated estimation of biological reference points for cod under different states of ecosystem in the Barents Sea. Besides, a further development of ecosystem approach is likely to be related to the incorporating of additional ecosystem reference points into the harvest control rules.
Therefore, it is possible to identify three successive stages to improve harvest control rules for cod in the Barents Sea applying ecosystem approach:

- the harvest control rules remain unchanged, but new values of biological reference points obtained with ecosystem based simulations are used;

- the existing scheme for calculation of TAC remains unchanged, but the values of biological reference points become variable depending on the situation in the ecosystem;

- new additional reference points and new scheme for stock management are applied.

The specification of optimal rules for cod stock harvest should be based on model calculations, which requires development of adequate management models. The use of differentiated values of biological reference points while deciding on TAC of cod presupposes prediction of ecosystem parameters dynamics, especially thermal conditions and feeding resources. The values of biological reference points calculated with the predicted parameters will have a higher uncertainty. This will lead to a larger gap between the values of limit reference point and corresponding precautionary reference point.

Estimation of economic efficiency of the stock harvest based on ecosystem strategy

The major purpose of stock harvest is a maximum income. Several long-term economic parameters that characterise the efficiency of stock harvest should be considered for estimation of the harvest strategy. These parameters can be obtained only with bioeconomic models. The development of such models is planned for the second stage of the joint PINRO and IMR programme for development of optimal ecosystem strategy for harvest of marine organisms in the Barents Sea.

Conclusion

The improvement of harvest control rules for cod is a prioritised task for fisheries research conducted in the Barents Sea. Ecosystem approach to harvest management as well as precautionary approach should ensure long-term sustainable and plausible harvest of marine biological resources. The developed 10-year programme for joint Russian-Norwegian research in this filed provides a good background for first practical advice on optimising harvest strategy for cod in the Barents Sea based on ecosystem approach already in the next three years.

One of the main tasks is to solve concept and methodology problems linked to implementation of ecosystem approach in the management of harvest in the Barents Sea. The lack of developed theory is an obvious obstacle to practical work. There is no common understanding of main principles for ecosystem approach to the management of marine biological resources. Besides, there is no clearly harmonised usage of terms and the proposed approaches to solve the practical problems are inadequate. Due to this, we need to unify definitions and methodical advice related to the ecosystem approach to the management of bioresources in the Barents Sea. It is also important that developed theoretical principles were discussed and agreed by ICES, which is the most competent international organisation responsible for advice on stocks management in the Barents Sea.

The main analytical tool for justification of ecosystem strategy for harvest should be multispecies and ecosystem based models intended for estimation of biological reference points and testing of different harvest control rules. The work on development of such models should be prioritised to improve management of marine biological resources based on ecosystem approach. There is a need to involve specialists in different fields in this work, for instance, mathematicians, biologists, oceanographers and economists, who work on stock assessment, species interactions, environment and harvest management.

Nowadays, there are different approaches to development of multispecies models in PINRO and IMR. The developed models differ both in concept and in structure. It is obvious that we should join efforts and unified approaches that will lead to a joint multispecies model for the Barents Sea. However, the ambition to create a joint model should not limit the range of possible optimal solutions. Such joint model can be based on more then one of the existing or developing models. To fuse several independent models developed by different groups of specialists could be a perspective approach to the creation of such model. In this case, a joint database should be used for all calculations and output data for one model should act as input date for other model.

A necessary requirement for development and effective use of multispecies models is a corresponding database. The Barents Sea is considered as a well-studied region. Extensive data on abundance, biology and trophic interactions between important for fisheries species as well as their feeding resources, hydrological conditions and fishing statistics were collected. Unfortunately, available historic data can be only partly used for multispecies modelling. A considerable part of biological data collected by PINRO before 1970s exists only on paper and is not available for computerizing. These data in electronic format could considerable expand possibilities for parameterization of multispecies models designed for the Barents Sea. Besides, the use of raw data is also an issue that lacks solution. The most perspective approach for it is to create joint Russian-Norwegian databases.

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